

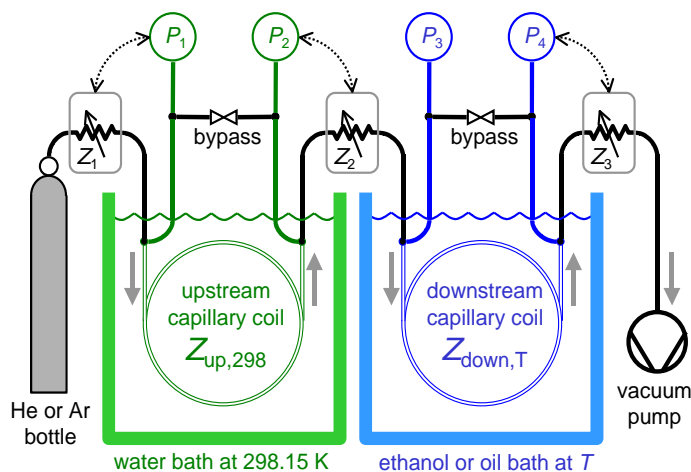
Reference Values of Gas Viscosity

NIST has refined techniques to produce reference values for the viscosity and thermal conductivity of argon with a standard uncertainty of only 0.08%. The viscosity of hydrogen, methane, and xenon will be obtained with similarly small uncertainties. The low uncertainty of these results also advances the fundamental models of intermolecular potentials.

M.R. Moldover, R.F. Berg, J.J. Hurly (Div. 836) and E.F. May (Guest Researcher)

The manufacturers of semiconductor devices and producers and consumers of natural gas rely upon accurate measurements of gas flow rates for equitable transfer in markets. The range of requirements differ by factors as large as 10^9 . Improved gas flow rate measurements increase confidence in market transactions and are enabled by gas property data of improved accuracy.

NIST's quantum mechanical calculations of the viscosity of helium [1,2] were combined with measurements made with two, newly developed viscometers. One viscometer [3] used a coil of quartz capillary tubing of high uniform diameter.



Schematic diagram of the two-capillary viscometer. The impedances Z_{up} and Z_{down} were coiled nickel capillaries with a length of 7 m and an inside diameter of 0.8 mm. The variable impedances Z_1 and Z_3 were piezoelectric gas leak valves and Z_2 was either a leak valve or a mass flow controller.

These are normally used for gas chromatography. During its operation, gas flows through the capillary, transducers measure the pressures at the entrance and exit, and a hydrodynamic model converts the pressure measurements to a flow rate value.

The second viscometer [4] used two capillaries in a series configuration, one maintained at 25 °C, and the other at temperatures ranging from 200 K to 400 K. Important features of the two-capillary viscometer include (1) electroformed nickel tubing with an extremely smooth internal surface, (2) voltage controlled piezoelectric leak valves, (3) pressure transducers maintained in thermostatically controlled enclosures, and (4) *in situ* calibration with helium at each temperature and time of use.

The two-capillary viscometer determined the ratio of the each gas's viscosity to that of helium, which is known with an uncertainty smaller than 0.1 %. For the noble gases argon and xenon, the measured viscosities were combined with calculations of the Prandtl number to yield the thermal conductivities with uncertainties of 0.08 % [4].

Both viscometers used a hydrodynamic model for capillary flow, also developed recently at NIST [5]. By incorporating the six most important corrections to the Hagen-Poiseuille equation for capillary gas flow, the model added negligible uncertainty to the final result.

The consistency of the measurements, and their agreement with the most accurate calculations of the viscosities of helium and argon, verified the accuracy of both viscometers. This improved measurement method has resulted in improvement in the accuracy of argon's thermal conductivity that is 30 times better than prior knowledge of this quantity. [6].

The new NIST reference values for viscosity and thermal conductivity will enable improvements of the thermal mass flow controllers that are used widely by the semiconductor industry.

Impact:

- This technique will enable accurate measurements of the viscosity of natural gas components at process and pipeline conditions.
- This technique could be extended as a cost-effective flow method to produce reference quality gas mixtures.
- Further work based on this technique would improve the models of the fundamental interactions between molecules. Extending the measurements to high pressures would provide the accurate data needed to develop reliable models of three-body collisions.

Future plans: Analysis of the measurements of hydrogen, methane, and xenon is near completion and will form the basis for publication of the results.

Publications and Presentations:

1. J. J. Hurly and M. R. Moldover, “***Ab initio* values of the thermophysical properties of helium as standards**”, *J. Res. NIST* **105**, 667-688 (2000).
2. J.J. Hurly, M.R. Moldover, and J.B. Mehl “**Improved *ab initio* values of the thermophysical properties of helium as standards**”, presentation at *Sixteenth Symposium on Thermophysical Properties*, Boulder, CO (2006).
3. R.F. Berg, “**Quartz capillary flow meter for gases**”, *Rev. Sci. Instrum.* **75**, 772-779 (2004).
4. E.F. May, M.R. Moldover, R.F. Berg, and J.J. Hurly, “**Transport properties of argon at zero density from viscosity-ratio measurements**”, *Metrologia* **43**, 247-258 (2006).
5. R.F. Berg, “**Simple flow meter and viscometer of high accuracy for gases**”, *Metrologia* **42**, 11-23 (2005) [erratum **43**, 183 (2006)].
6. E. W. Lemmon and R. T. Jacobsen, *Int. J. Thermophys.*, **25**, 21-69 (2004).